The Building Blocks for JWST I&T to Operations – From Simulator to Flight Units

Curtis Fatig[a], William Ochs[a], Alan Johns[a], Bonita Seaton[b], Cynthia Adams[b], Francis Wasiak[*a], Ronald Jones[a], Wallace Jackson[c]

[a]Goddard Space Flight Center, Code 443, Greenbelt, Maryland 20771, USA; [b]Goddard Space Flight Center, Code 580, Greenbelt, Maryland 20771, USA; [c]Northrop Grumman Aerospace Systems, One Space Park, Redondo Beach, CA 90278, USA

ABSTRACT

The James Webb Space Telescope (JWST) Project has an extended integration and test (I&T) phase due to long procurement and development times of various components as well as recent launch delays. The JWST Ground Segment and Operations group has developed a roadmap of the various ground and flight elements and their use in the various JWST I&T test programs. The JWST Project's building block approach to the eventual operational systems, while not new, is complex and challenging; a large-scale mission like JWST involves international partners, many vendors across the United States, and competing needs for the same systems. One of the challenges is resource balancing so simulators and flight products for various elements congeal into integrated systems used for I&T and flight operations activities.

This building block approach to an incremental buildup provides for early problem identification with simulators and exercises the flight operations systems, products, and interfaces during the JWST I&T test programs. The JWST Project has completed some early I&T with the simulators, engineering models and some components of the operational ground system. The JWST Project is testing the various flight units as they are delivered and will continue to do so for the entire flight and operational system. The JWST Project has already and will continue to reap the value of the building block approach on the road to launch and flight operations.

Keywords: integration and test, JWST, simulators, operations

1. INTRODUCTION

1.1 JWST Background

The JWST, shown in Figure 1, is a large aperture infrared space telescope with a five-year mission, ten-year design goal. It is currently planned to be launched in 2018 from French Guiana aboard an Ariane 5 launch vehicle. The JWST is designated to succeed the Hubble Space Telescope (HST) and the Spitzer Space Telescope as part of the NASA Great Observatories program. The JWST will continue the HST tradition of advancing breakthroughs in our understanding of the origins of the earliest stars, galaxies, and the very elements that are the foundations of life. The JWST team includes several partners at multiple locations: (1) Project management located at Goddard Space Flight Center (GSFC), (2) Observatory prime contactor (Northrop-Grumman Aerospace Systems (NGAS)), (3) Integrated Science Instrument Module (ISIM) located at GSFC, (4) Near-

Figure 1 – JWST Model at Goddard Space Flight Center.

*francis.c.wasiak@nasa.gov; phone 1 443 286-2252

Infra Red Camera (NIRCam) (University of Arizona and Lockheed Martin), (5) Near-Infrared Multi-Object Spectrometer (NIRSpec) built in Europe, (6) Mid-Infrared Instrument (MIRI) build by a US and European team, (7) Flight Guidance System (FGS) built in Canada and (8) Science and Operations Center (S&OC) located at the Space Telescope Science Institute (STScI) located in Baltimore MD.

From a ground system perspective, the JWST mission is a fairly traditional science mission. For operations, the JWST will be located at the second Sun-Earth Lagrange Point (L2), see Figure 2, which provides the JWST with a naturally cold environment with no solar eclipses and an unobstructed view of the earth for communications. After launch and commissioning, normal operation will involve two 4-hour contacts per day to allow the uploading of commands, monitoring of real-time engineering telemetry, and downlinking of engineering and science data from the solid state recorder (SSR).

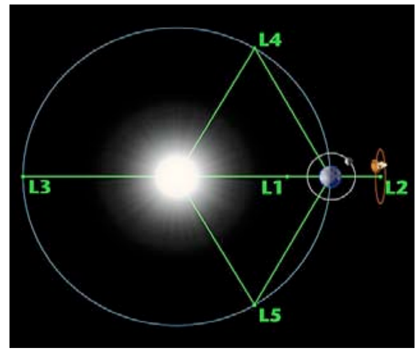

Figure 2 - Lagrange Points.

The I&T and operational phases of the JWST are projected to span 15 and 10 years respectively. Given this long development phase and to assure ourselves that anything that will effect operations is found early in the test programs, a building block approach was used.

The mission systems are divided into two segments: Observatory and Ground. The Observatory is decomposed into three elements: the spacecraft, the Optical Telescope Element (OTE) and ISIM. The Ground Segment is constituted from two operational elements: the Institutional Systems (Deep Space Network (DSN), Flight Dynamics Facility (FDF) and networks and launch support assets) and the S&OC.

With both Segments contributing to the foundation of systems and simulators needed to support and evolve from I&T to operations, four test phases were identified as key divisions for the migration from I&T systems to operational systems. These four test phases are: Certification Laboratory Testing, ISIM I&T, joint OTE/ISIM (OTIS) I&T and Observatory I&T. With each phase, the fidelity of the components used in testing increases. Early testing is performed mainly with simulators, with an increasing amount of operational systems utilized in the later states of testing. See Figure 3 for an estimation of the fidelity level per test phase.

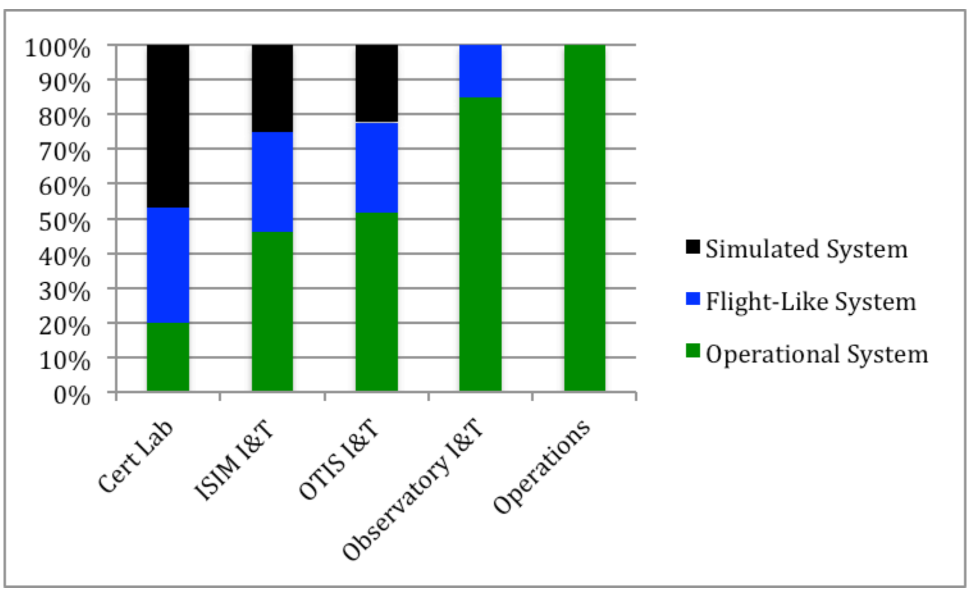

Figure 3. System Fidelity Increases through Test and Operational Phases

2. DEFINING THE BUILDING BLOCKS

2.1 Integrated Science Instrument Module

The ISIM contains the science instruments, the fine guidance sensors, and their supporting structure, thermal support systems, control electronics, and the ISIM command and data handling system (ICDH).

ISIM command and control product testing begins with a combination of simulated and flight-like (i.e., engineering models) ISIM components in the certification lab testing phase. During this test phase, detector, focal plane electronics, and fine guidance sensor simulators represent the science instruments. Power and thermal simulators, a flight-like ICDH, and an early version of ISIM flight software represent the rest of the ISIM for certification testing.

The recent delivery of the MIRI flight model to the GSFC begins the integration of the instruments to the ISIM. The subsequent instrument flight model deliveries will allow the full integration of the instruments to the flight structure, power, thermal, and ICDH components. The ISIM I&T phase will exercise all flight models with a flight software build reflective of the needs for ISIM I&T.

Following ISIM I&T, the ISIM element will be integrated with the OTE during OTIS I&T phase at the Johnson Space Center with an ISIM flight software build reflective of the OTIS I&T needs. Finally, the ISIM and OTE will be integrated with the spacecraft at the NGAS facility during Observatory I&T. The ISIM flight software build for Observatory I&T will be the same as that used for operations.

2.2 Optical Telescope Element

The OTE consists of the Primary Mirror, consisting of 18 hexagonal segments, as well as secondary, tertiary, and fine steering mirrors.

During certification testing, the instrument simulators read image files that are representative to some of the source images that will be captured by the OTE during operations. For ISIM I&T, OTE will be represented by the Optical Simulator (OSIM) that will provide simulated point source/star images for optical performance testing of the ISIM. The full OTE will be integrated with the ISIM during the OTIS I&T phase.

2.3 Spacecraft

Spacecraft component development occurs concurrently with ISIM I&T. Therefore spacecraft I&T trails ISIM I&T, occurring roughly in parallel with OSIM I&T. This schedule requires the use of spacecraft component simulators and engineering models for early test phases.

Certification testing is done strictly with a simulated SSR and electrical power system components, an off-the-shelf version of the command and telemetry processor and a flight software build that provides basic interface functionality. Together, these simulated components are known as the Spacecraft Simulator-1A (SCSim-1A). Upgrades in support of ISIM and OTIS I&T include an engineering model of the command and telemetry processor and a quarter-size engineering model of the SSR. These upgrades along with a new flight software release makes up the high fidelity spacecraft simulator, known as the Spacecraft Simulator-2A (SCSim-2A). With the completion of the spacecraft I&T phase, the full spacecraft with all of its components' flight models will support the integration of OTIS with the spacecraft in Observatory I&T. The spacecraft flight software build used for Observatory I&T will be the same as that used for operations.

2.4 Institutional Systems

The JWST Project's Institutional Systems are made up of NASA communication networks, including the Deep Space Network (DSN) and the Communications Services Office (CSO). The DSN is augmented by NASA's Space Network (SN) and the European Space Agency (ESA) Tracking Network (ESTRACK) for early flight-to-ground communication support. The GSFC Flight Dynamics Facility (FDF) is another system in the Institutional Systems element.

Certification testing does not require any communication networks, simulated or otherwise. During ISIM and OTIS I&T testing, communication between the command and control system and the spacecraft simulator are performed through the Telemetry & Command and Mission Telemetry Test Sets. These test sets decode, decommutate, and preprocesses telemetry; provide science data processing, and format and transmit commands received from the command and

telemetry system. The communication networks become flight-like during Observatory I&T with the introduction of the DSN and SN radio frequency (RF) compatibility trailers. During this testing phase, the operational ground communication lines provided by CSO link the communication networks to the S&OC. An RF test set is also utilized during Observatory I&T, providing uplink and downlink signal demodulation between the Observatory I&T facility and the communication networks.

2.5 Science and Operations Center

The S&OC is responsible for operating the JWST Observatory and enables scientists to plan and complete their scientific investigations. The JWST Project chose early on to use the same command and telemetry system and database from systems integration through launch and normal operations. This concept eliminates the effort to provide separate ground systems and databases for each development phase and supports the Project's 'test as you fly' philosophy. These *common systems* are the precursor to the S&OC and are deployed for instrument and spacecraft development and I&T efforts prior to the S&OC being stood up. The command and telemetry system is known as the Common Command & Telemetry System (CCTS); the database is known as the Project Reference Database (PRD). The PRD contains all configured data used to develop, test, and operate the Observatory.

The command and telemetry system and the database are considered operational systems at the time of certification testing. Additional tools, known as the Integrated Ground Support Systems (IGSS), needed for early testing, will migrate to the operational system at the S&OC. These include telemetry trending, science pipeline, and database tools. The final key components of the S&OC components are the Operations Scripts Subsystem (OSS) and the Proposal Planning Subsystem (PPS). The OSS is comprised of on-board scripts that execute JWST event-driven operations; the PPS performs the planning and scheduling of JWST observations.

Figure 4 provides a pictorial view of the transition from I&T to operations and the reuse of the I&T systems. Phase 1 included early hardware and software development; phase 2, shown in light brown, shows those capabilities added for I&T efforts; and phase 3 shows the operational systems. This transition builds upon the previous phases to reduce the data translations, user training, and risk to the eventual operational system.

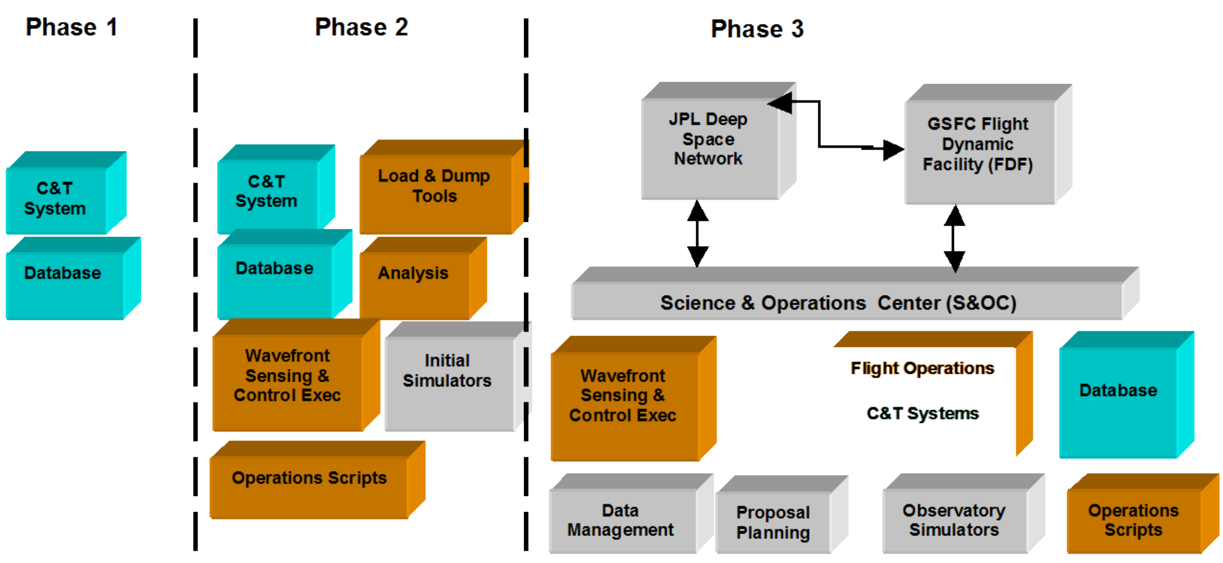

Figure 4. Core Common Systems

During the certification testing, the command and telemetry system and the database are utilized along with the flight-like IGSS tools and an I&T data archive system. In addition, ISIM I&T utilizes the full PRD Subsystem (PRDS), including the database and the tools required to manage it, portions of the Wavefront Sensing & Control (WFS&C)

Software Subsystem (WSS), and the onboard scripts that were certified for use during the certification testing. OTIS I&T requires the use of the full WSS as well as additional onboard scripts. It is during OTIS I&T that the S&OC is ready to start fully participating in I&T activities. During this phase, the majority of command and control will occur with the ground elements local at JSC, but a subset of activities can be conducted remotely from the S&OC. During Observatory I&T, the S&OC is complete with the addition of full OSS and PPS subsystems and with the science pipeline and data archive functions being fully incorporated into the Data Management Subsystem (DMS).

3. DEFINING THE FIVE TEST PHASES

The JWST Project identified four test phases to transition from Integration and Test (I&T) to launch, and finally operations. These four test phases are: Certification Systems, ISIM I&T, OTIS I&T, and Observatory I&T. With each test phase, the fidelity of the components used in testing increases. Early Certification Systems mainly use simulators for testing. During ISIM and OTIS I&T, instrument and OTE flight models are used, whereas the spacecraft is still simulated. During Observatory I&T, flight models are used for instruments, OTE and spacecraft components. The Operations Phase starts with GO/NO-GO for launch and continues with six months of commissioning and 10 years of operations. With 'test-as-you-fly' as a mandate, the Ground Segment contains the operational command and telemetry system, onboard scripts, and database for all phases. This allows for early I&T and operational command procedures development. As the test phases continue, more and more Ground Segment components and operational products become operational.

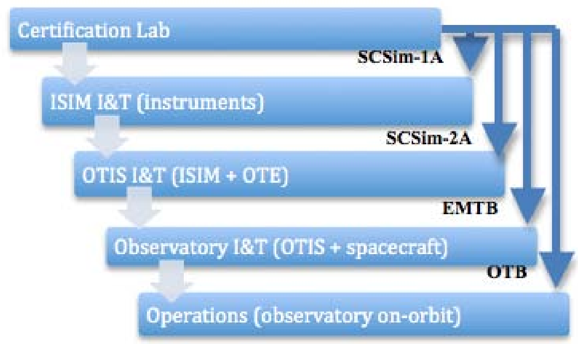

Figure 5. JWST Test Flow

3.1 Certification Laboratory Testing

The GSFC Certification Laboratory is made up of the Ground Segment's common systems of the command and telemetry system and database, the integrated ground support system, SCSim-1A, and a flight-like ISIM command and data handling system. It is used for the testing and certifying of preliminary on-board scripts (even-driven operations), developing, testing, and certifying of command procedures for ISIM and OTIS I&T and flight operation (test-a-you-fly), and early testing of the Ground Segment to Observatory interfaces. During the end of this phase all ground segment and operations data products (commands, telemetry, command procedures, on-board scripts) to be used during ISIM I&T have been certified to executed against flight models.

Additional certification testing occurs throughout the test phases and on-orbit operations through the use of higher-fidelity spacecraft simulators, including the SCSim-2A used for OTIS I&T, the Engineering Model Test Bed (EMTB) resident at the spacecraft manufacturer's facility for Observatory I&T, and the Observatory Test Bed (OTB) resident at the S&OC for on-orbit operations.

3.2 Integrated Science Instrument Module Integration and Testing

During the ISIM I&T, the ground common systems will be used to test all the JWST instrument flight models, the ISIM command and data handling system and flight software. The addition of the spacecraft simulator, SCSim-2A, with engineering models and the OTE Simulator (OSIM) enables flight-like interfaces for the science instrument integrated system. This phase will be used to test, and verify on-board scripts and command procedures with the instrument flight hardware at ambient and cryogenic temperatures. Any ground segment and operations data products executed against instrument flight models will be certified for operations (test-as-you-fly). It also covers testing with S&OC subsystems as they become available (test-as-you-fly), such as the WSS.

3.3 OTIS Integration and Testing

During the OTIS I&T, the ground common systems and the SCSIM-2A will be used to test the integrated flight ISIM (instruments and instrument computer) and the OTE at the Johnson Space Center. Included are test activities used to

exercise, test, and verify the on-board scripts and command procedures with the flight hardware at cryogenic temperatures. It also covers testing with other S&OC subsystems, which may include the WSS, DMS and PPS.

3.4 Observatory Integration and Testing

During the Observatory I&T, the ground common systems will be used to test the integrated flight observatory. The observatory includes: all spacecraft subsystems, ISIM and OTE. The ground system testing during Observatory I&T will be at the spacecraft manufacturer facility. It includes test activities used to exercise, test, and verify the on-board scripts and command procedures with the spacecraft, OTE and ISIM flight hardware. During this phase Ground Segment Institutional Systems use test vans and RF test sets via the operational network. The Ground Segment S&OC components are all operational except for a few supporting tools.

3.5 Operations

For the Operations Phase, all Observatory and Ground Segment components are operational systems. It includes test cases to verify mission readiness and to prepare operations staff to operate the JWST Observatory and ground segment. All elements of the Ground Segment will be verified at an end-to-end level. Mission and compatibility tests between the Ground and Observatory Segments will be performed to verify real-time command and control of the Observatory and that telemetry can be received, processed and displayed in the S&OC. Mission rehearsals and training exercises are conducted using the OTB for verification and demonstration of the operations team ability and readiness to support commissioning operations. The OTB incorporates engineering models to provide a high-fidelity simulation of the observatory. The OTB will interface to the S&OC's command and telemetry system through a COTS Front End Processor (FEP). The FEP formats Consultative Committee for Space Data Systems (CCSDS) command and telemetry packets. Once the observatory is launched, the observatory manufacturer has six months to commission and certify the observatory before handover to NASA. Once handover is complete, the ten years of operations begins.

4. PUTTING IT ALL TOGETHER

The following JWST end to end progress flow (figure 6) shows the building block approach for the five test phases and how the entire system (Observatory and Ground Segments) is tested before launch. It starts in the Certification Lab and ends with pperations, showing components progressing from simulated systems to flight-like systems to finally operational systems. Along the way, ground common systems are used during every phase to verify not only the ground system components, but also the operational products (command procedures and on-board scripts).

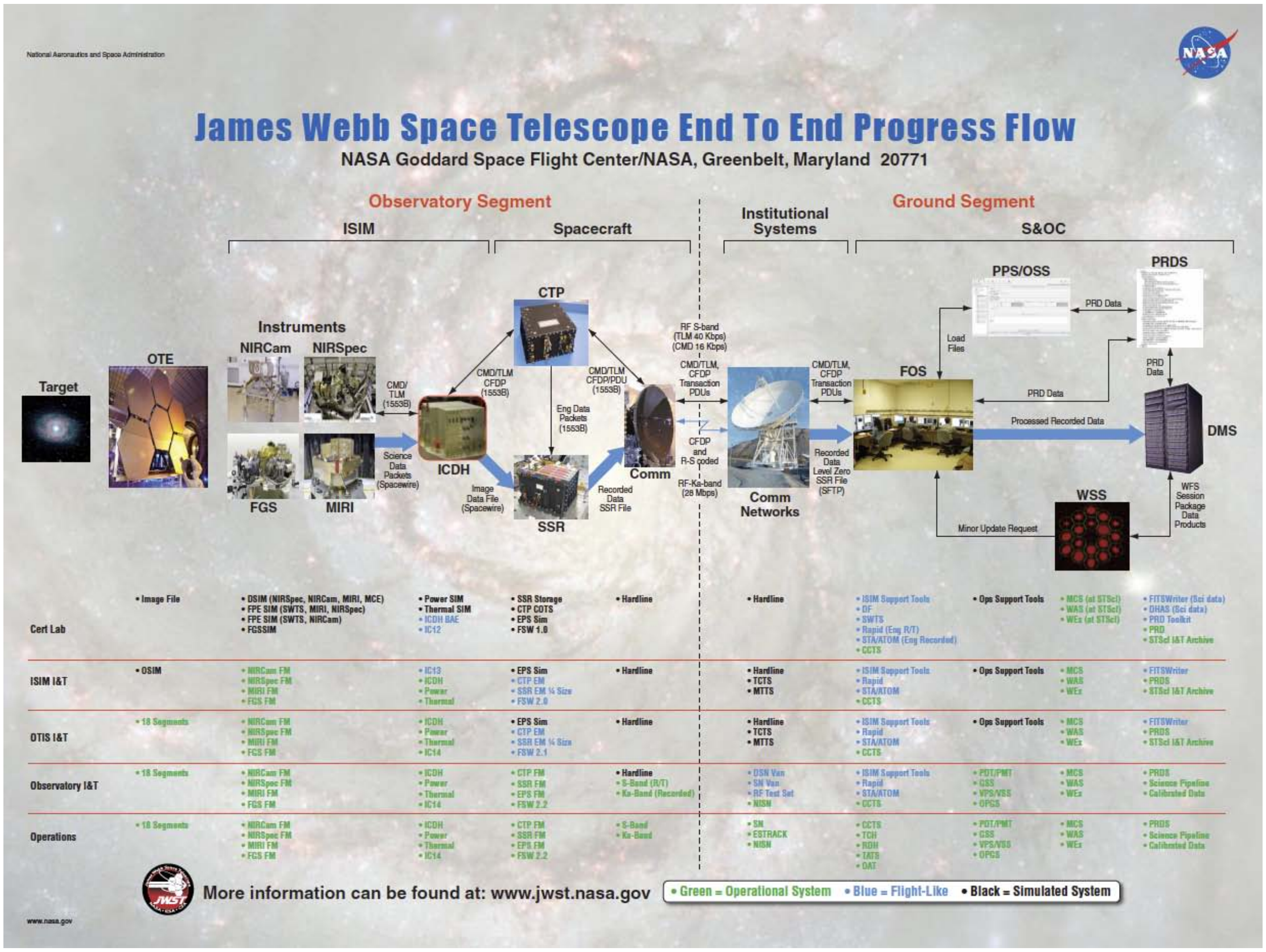

Figure 6. JWST End To End Progress Flow

5. SUMMARY

With the JWST integration and test activities occurring in multiple locations and spanning an extended period of time, the building block approach instituted by the JWST Project is proving to be beneficial. The same ground system components are being utilized across all I&T locations and through all phases, simulators and engineering models substitute for flight models during early testing phases and an increase in fidelity occurs as the Observatory is built up. This approach requires significant planning, from refreshes of ground system computers, to the scheduling of simulator, engineering model and flight model deliveries and the integration of the whole system for each phase.

Although this model works well for a complex, one of a kind mission like the JWST, it isn't the model to follow for all missions. Less-complex spacecraft or spacecraft in series can afford a more traditional linear, streamlined timeline.

This building block approach has been very successful so far, due in large part to all of the JWST team working towards a successful mission as one team, doing the right activities, in a timely fashion.